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CONCEPTUAL THINKING[1]

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IN the recent newspaper controversy concerning evolution, one of Mr. Bryan's supporters displayed some impatience at the emphasis placed by scientists on resemblances. He protested in the name of logic against what seemed to him an undue insistence on resemblance, resemblance, resemblance! But unless we take account of the similarity among phenomena, how are we to arrange and classify the data of physics, chemistry, botany and zoology, or arrive at the concepts of which the propositions and syllogisms of the logician are composed? We can have no science of distinct existences ununited by the bond of likeness. It is only by virtue of resemblances that we are enabled to pass from the observation of particulars to the consideration of universals. Bain and other psychologists are so far from belittling the ability to discover the bond of similarity among phenomena, often apparently unlike, that they regard it as characteristic of the man of genius. For James, genius is the possession of similar association to an extreme degree. To the type of genius that *notices* the identity underlying cognate thoughts belong the men of science, and it is in the concept that the conscious identification takes place.

Conception, or the cognition of the universal aspects of phenomena, can be illustrated from the history of the biological sciences. For example, what Linnaeus called the "System of Nature" was in reality a system of concepts. His classification of plants, though it prepared the way for more natural classifications, was crude, because based on superficial similarities. He, as Harvey-Gibson says, "elaborated a complex and beautifully arranged and catalogued set of pigeon-holes and forced the facts that Nature presented to him into these pigeon-holes, whether they fitted the receptacles or not." His zoological concepts were likewise inadequate. Suffice it to recall his vague use of the terms *Insecta, Vermes* and *Chaos*. The likenesses revealed in animal structure by the comparative anatomists from Hunter to Cuvier and Owen led to a sharper definition of concepts and a more satisfactory classification. Paleontology afforded new materials for

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comparison. Lamarck introduced the term *Invertebrate*. Embryology and the use of the microscope led to fresh observations of likeness and to the establishment of the natural affinities of species and genera. Here might be mentioned particularly the discovery of the notochord—the key, as it has been called, of vertebrate anatomy—and the consequent use of the term *Chordata*. The coming of evolution made possible a phylogenetic classification of organisms and a subtler differentiation of biological concepts.

The dominance of conceptual thinking in the classificatory aspects of science is fairly obvious. For example, in adopting the terms *Quercus alba, Q. rubra* and *Q. salicifolia,* the seventeenth-century taxonomist merely associated a definite nomenclature with the distinct concepts of Virginian woodmen, who had observed the likeness of American and British oaks. In other aspects of science, where the importance of the concept is far less obvious, it is none the less real. In the study of human anatomy by means of dissection it is generalized or conceptual knowledge that one seeks and retains. Anomalous or exceptional structures—such as a triceps muscle in place of a biceps, or an over-developed *panniculus carnosus*—are either disregarded and forgotten, or remembered as anomalies and exceptions. In any case, what the student retains, after two years spent in the dissecting-room, is a generalized knowledge of the structure of the human body and not a memory of the particular cadavers that seemed to occupy the focus of his attention. The case is somewhat similar with your natural history museum. The biological collections consist wholly of dead symbols of living things. Bones are frequently represented by masses of limestone or silica. A single specimen may do duty for a species, genus or order. The mere external surface—the shape—may alone be preserved. Only one stage in an animal's development may be exhibited, or only one posture—the Megatherium pulling down a tree or a dinosaur in a more or less characteristic pose. Each specimen has value not as representing an individual but as symbolizing a group. Each concrete object, like a word in a catalogue, serves to recall a concept.

The importance of cultivating the habit of conceptual thinking has been definitely recognized since the time of Plato, and Plato's master, Socrates. The majority of people, according to the Platonic dialogues, are the slaves of their senses and never attain to a system of clear concepts. They fail to translate their perceptions into conceptions and to pass from the sensible world to the supersensible or intelligible world. Plato valued the sciences with which he was best acquainted—mathematics and astronomy—because they tend to wean the mind from what is sensory and transitory to what is conceptual and eternal. The concept triangle,

the triangle of definition, is more real than any of its visible representations. Discipline in conceptual thinking is perferable to utility. "You amuse me," he writes, "by your evident alarm lest the multitude should think that you insist upon useless studies. Yet, indeeed, it is no easy matter, but, on the contrary, a very difficult one, to believe that in the midst of these studies an organ of our minds is being purged from the blindness, and quickened from the deadness, occasioned by other pursuits—an organ whose preservation is of more importance than a thousand eyes; because only by it can truth be seen."

Plato's philosophy is interesting for us because modern science is just such a system of clear concepts as he had in mind, and it is a mistake to interpret his intelligible world as something invisible to-day but accessible to the senses at some future time. The scientist must turn away from the sensuous world of the artist and the child to the intelligible world of mathematics, physics and biology; from the eight or seven little boys seated on a fence to cube root and prime numbers; from the panorama of many-colored nature to the conceptual world of elements, atoms, ions and electrons. The sciences are a sort of shorthand way of conceiving phenomena. They do not give us nature in its richness and fullness. In the words of Mephistopheles, "Gray, dear friend, is all theory, and green the golden tree of life." Picturesqueness is sacrificed by the scientist for the sake of clearness and economy of thought. He casts his net now for one kind of fish, now for another. For an artist like Monet, water may be a shimmering variegated surface; for the child it may mean "to drink;" while for the chemist it may be H_2O, or, if he conceives it as an alcohol, H.OH.

Of course science has no monopoly of clear conceptions. In insisting on the value of an education in conceptual thinking, Plato had in mind the training of leaders in ethics and statesmanship, and thus anticipated by a few centuries the publicists and philosophers who to-day advocate, as a novelty, the application of the intellect in social and political reform or proclaim the cultivation of the scientific habit of mind as the sole means of maintaining and advancing contemporary civilization. He would have recognized Lincoln as a man of clear conceptions, gained through a unique self-education, by living in close contact with man and nature, by reading a few books with extraordinary care, by poring over the statutes of Indiana, studying grammar, arithmetic and surveying, conning the dictionary, passing in review the life of Washington and the history of the United States, following with a frontiersman's imagination the exploits of Robinson Crusoe, absorbing the wisdom of Aesop's Fables, weighing the moral principles of The Bible and The Pilgrim's Progress. Indeed,

clear conceptual thinking, the scientific habit of mind, was consciously cultivated by the moral philosophers of Greece, notably by Socrates, whose chief distinction is that he subjected to critical examination such concepts as virtue, temperance and justice. Speaking of this pioneer work, Stout says: "It is only at a late stage of mental development that an attempt is made to distinguish an identical or persistent element of meaning pervading the varying significations of a word. When the attempt is made, it constitutes an epoch in the history of thought. It is the beginning of definition and of the scientific concept."

Conception, or thinking the same in like circumstances, has its complement in discrimination. Association by similarity is offset by dissociation, integration by disintergration, synthesis by analysis, and the observation of congruity by the observation of incongruity. In this respect, there is a marked difference between one individual and another. Experiment shows that one student may recognize readily ten shades of gray where his classmate has the greatest difficulty in discerning any difference in shade whatever. Similarly, one mind is alive to shades of meaning that make no impression on another. Aristotle, the greatest of all scientific intellects, trained for twenty years in the school of Plato in conceptual thinking, the most acute among the Greeks, as he has been called, in noting differences and making distinctions, carried his investigations into almost all the realms of knowledge. His success was most marked in fields where his aptitude in the employment of general concepts was supported by a wealth of observational data. This is particularly remarkable in his researches in biology. In the *Historia Animalium,* for example, one discovers the trained thinker bringing order out of chaos by the application of the intellect to the facts of experience, so called. It is the custom among historians of a conservative type to belittle the medieval followers of Aristotle, and above all the scholastics. But even to scholasticism modern science is deeply indebted for the development of logic in general, and for the definition and differentiation of concepts in particular.

The use of language is the indispensable concomitant of clear conceptual thinking. We can not think of one of the lower animals advancing very far in logical thought. He is bound down for the most part to the fleeting images of things, and lacks the word (logos) by which they might be made permanent and independent of the continuum of experience. The intellectual development of the child proceeds as a rule *pari passu* with its command of appropriate terms. "Out of hundreds of English-speaking children," says Terman, "we have not found one testing significantly above age who had a significantly low vocabulary;

and, correspondingly, those who test much below age never have a high vocabulary. Occasionally, however, a subject tests somewhat higher or lower in vocabulary than the mental age would lead us to expect. This is often the case with dull children in cultured homes and with very intelligent children whose home environment has not stimulated language development. But even in these cases we are not seriously misled, for the dull child of fortunate home surroundings shows his dullness in the quality of his definitions, if not in their quantity; while the bright child of illiterate parents shows his intelligence in the aptness and accuracy of his definitions.'' Terman thus makes it clear that intelligence is not to be gauged by the extent of one's vocabulary, but by the exactness with which concepts are defined.

In the interests of the progress of both science and democracy, it is important that training in the precise use of words—especially the derivatives of those languages from which we draw our general concepts—should not lag behind other conditions of the development of the immature. As Walter Lippmann says, ''Education that shall make men masters of their vocabulary is one of the central interests of liberty.'' Franklin's success, both as a statesman and a scientist, was in no small measure owing to the severe drill in the use of the English language to which he subjected himself. Two other self-educated research men, namely, John Hunter and Michael Faraday, who, on first thoughts, might seem to bear witness against the view that language training is of importance in scientific investigation, prove on examination to furnish testimony in corroboration. John Hunter received little if any schooling. He turned in contempt from the opportunity of studying the classics at Oxford. Although, after reaching maturity, he was brought, through the closest association with his brother, William Hunter, in contact with scholarly traditions, he never overcame the defects of his early education. We are indebted to him for such concepts as ''arrested development'' and ''secondary sexual characters,'' but his pages are strewn with terms like ''the stimulus of death,'' ''the stimulus of imperfection,'' and ''sympathy,'' to which he assigned a significance now impossible to recover. The lack of language training, in spite of Hunter's genius and vivid personality, was detrimental to his influence as a lecturer and writer. Owing to this shortcoming, science has not yet reaped the full harvest of his tireless energy in research. For example, the recapitulation theory, as stated by him, seems to-day little more than a literary curiosity, though it may have influenced the progress of embryology through the interpretation of the younger Meckel. The case of Faraday was somewhat different from that of Hunter. Having received an elemen-

tary education, Faraday became apprenticed to a book-binder. For years he spent his leisure time in reading scientific works. At the age of twenty-one he gained the favor of Sir Humphry Davy by a lucid report of some lectures delivered by Davy at the Royal Institution. Faraday became Davy's assistant, traveled on the Continent with his patron, studied foreign languages, and made definite efforts to acquire the oratorical arts of Davy, a recognized master of scientific diction. Faraday's opportunities for language training, however, came just a little too late. He sometimes confessed his difficulty in formulating the ideas that occurred to him. He sought aid at the University of Cambridge and was indebted to Whewell for such terms as "electrolysis," "electrolyte," "ion," etc.

Language permits us to summarize nature, to express it schematically, to seize upon certain aspects of it—that is, to analyze phenomena with certain purposes in view. For Priestley the part of the atmosphere that supports life was "pure dephlogisticated air." Lavoisier substituted a new term and a new conception, viz., "oxygen." Davy spent a great deal of time proving that Lavoisier had a false conception of the element discovered by Priestley. We retain the name after having modified the concept. This we do with the greater freedom, seeing that the classical term "oxygen" is not self-explanatory, as is the analogous term "Sauerstoff." Gases were known in the last quarter of the eighteenth century as "kinds of air," or "factitious airs." As late as 1766, Cavendish called hydrogen "inflammable air." In 1783 and 1785, he made experiments that justify the conceptions expressed by the terms "hydrogen" and "nitrogen." It was almost impossible to think clearly concerning earth, air, fire, and water, the so-called elements, without having the terms "oxygen," "nitrogen," "hydrogen," etc., as symbols of the concepts corresponding.

Counting, measuring, weighing—the application of mathematics—must be regarded as among the best means of sharpening up our conceptual thinking. One classical example is Lavoisier's use of the balance in establishing the nature of combustion and giving phlogiston the quietus. "About a week ago," he wrote on November 1, 1772, "I discovered that sulphur in burning, so far from losing weight, rather gains it; that is to say, that from a pound of sulphur more than a pound of vitriolic acid may be obtained, allowance being made for the moisture of the air. It is the same in the case of phosphorus. The gain in weight comes from the prodigious quantity of air which is fixed during the combustion and combines with the vapors. This discovery, which I have confirmed by experiments that seem to be decisive, has made me believe that what is observed in the combustion of sulphur and

phosphorus may equally well take place in the case of all those bodies which gain weight on combustion or calcination. I am persuaded that the gain in weight of the metallic calces is owing to the same cause.'' Lavoisier followed up this work by the calcination of tin in 1774, and in the same year—after Priestley's discovery of ''pure dephlogisticated air''—by the oxidation of mercury. In 1777, Lavoisier stated: that in all cases of combustion heat and light are evolved; that bodies burn only in oxygen (or *air éminement pur,* as he at that time called it); that oxygen is used up by the combustion, and the gain in weight of the substance burned is equal to the loss of weight sustained by the air.

The differentiation of terms and concepts is so necessary an accompaniment of the advance of science that no collection of examples can be regarded as adequate or as even fairly representative. Though Lavoisier in 1777 succeeded in giving to the concept ''combustion'' a much more clearly defined meaning than had attached to the ''fire'' of the ancient philosophers or the ''flame'' of Francis Bacon, in 1789 he still included ''caloric'' and ''light'' in his table of elements. In spite of the definition by Robert Boyle of the concept ''element,'' and the attempt of Newton to determine the meaning of ''atom,'' these ideas, inherited from the remote past, were at the close of the eighteenth century about to enter on a new series of transformations. In the seventeenth century Boyle's contemporary, John Ray, ascribed to the term ''species'' a definite, if not a final, significance, and Sydenham, seeking to establish by clinical observation distinct species of disease, succeeded in differentiating measles from smallpox, in defining chorea, in modifying the significance of the term ''hysteria,'' etc. Progress in science may involve lessening or increasing the extension of a familiar term, determining anew the distinction between familiar terms, and introducing new clearly defined terms. Pasteur's studies in molecular asymmetry involved a reconsideration of the terms ''tartrate'' and ''racemate'' and a delimitation of the concepts which each of these terms expressed. An advantage is gained by substituting the unfamiliar ''neurasthenia'' for the familiar ''nervousness,'' partly because the new term is unambiguous and partly because it is devoid of every popular connotation. In fact, our scientific terminology has become so much a thing apart that one may overlook the relationship between a common term like ''weight'' and a more technical term like ''mass.''

The researches of Schleiden and Schwann, which led up to the statement of the cell theory, were affected and, to some extent, vitiated by traditional conceptions concerning ''cellular tissue'' and the ''cell.'' Robert Hooke was the first to use the term ''cell''

in describing organic structure. He had examined charcoal, cork, and other vegetable tissues under the microscope and described them in 1665 as "all perforated and porous, much like a honey-comb." He could discover no passages between the minute cavities or cells, though he took it for granted that the nutritive juices to be seen in the cells of green vegetables had some means of egress. Hooke's observations were verified by his contemporaries. Grew, in describing the microscopic structure of plants, mentioned the infinite mass of "little cells or bladders" of which certain parts are composed, and Malpighi described the cuticle of the plant stem as consisting of "utricles" arranged horizontally. Caspar Wolff in his doctor's thesis (*Theoria Generationis,* 1759) reported the observation of cells and "little bubbles" which developed in the homogeneous layers of the embryo. In the works of Bichat, the founder of histology, the term "cellular tissue" was used, as indeed it is to-day, to indicate a certain kind of connective tissue. Treviranus and Link described the cells in vegetable tissues in 1804, the latter maintaining that they are closed vesicles incapable of communicating with each other. Professor John H. Gerould has recently pointed out, in the pages of *The Scientific Monthly,* the important part taken by Lamarck, Mirbel (the disciple of Caspar Wolff), and others in the development of the conception of the "cell" and of "cellular tissue." After the appearance of Moldenhawer's *Contributions to the Anatomy of Plants* (1812), which demonstrated that the cavities of vegetable cells are separated from each other by two walls, the attention of observers was diverted from the cell contents to the cell wall. The consequent misconception of the nature of the cell was in part corrected by Robert Brown's discovery of the cell nucleus and by the later discovery of protoplasm. It was before the full significance of the cell contents was realized that the cell theory was conceived by Schleiden and Schwann.

It is evident that advances in scientific thinking imply the use of clear concepts and clear terms. The term "neuron," employed by the early Greeks in the sense of "thong" or "sinew," was applied by the anatomists of the fourth century B. C. to the tendon as well as to the nerve. A considerable treatise alone would suffice to trace its subsequent meanings and those of its derivatives and at the same time to give an account of the investigations that from the time of Herophilus and Erasistratus have contributed to the elucidation of the concepts in question. The terms that represent to-day the so-called chemical elements have no doubt undergone a similar series of transformations in meaning. Distillation, crystallization, and other refining processes had to be brought into play before the concept—the spirit, the essence, the thing in itself—could be realized.